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Multi-objective optimization tool for shell-and-tube heat exchanger design

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Abstract Heat exchangers (HE) are widely used in many different industries. The multi objective optimization of HE provides an avenue for improved efficiency and a reduction of cost. In the present work, a multi objective optimization tool for shell-and-tube heat exchanger design has been developed. The thermal calculation is described based on the log-mean-temperature-difference (LMTD) method and the effectiveness-NTU method. A multi objective optimization procedure based on two evolutionary optimization algorithms, non-dominated sorting genetic algorithm (NSGA-II) and teaching-learning based optimization (TLBO), is also implemented. Maximization of effectiveness and minimization of cost are identified as key objective functions applicable to most engineering problems and used as the objective functions for multi objective optimizations. This tool provides a user-friendly input panel of all parameters as well as a graphical output of the results. The results are validated against the examples in the literature.

Keywords: Heat exchanger, Multi-objective optimization, Shell and tube, Evolutionary algorithm

1. Introduction

Heat exchangers are fundamental components of many thermal systems used within a broad spectrum of engineering industries. The design of a heat exchanger (HE) can be complex, with many variables to consider. Once a suitable heat exchanger design has been defined, optimization methods can dramatically improve HE design according to the principle design goals. In reality, most design cases require an interlinked solution for the maximum effectiveness within a specified budget/cost or dimensional requirement. This solution can be found through a multi-objective optimization procedure.

Recently, evolutionary and natural processes to produce the best optimization algorithms have been focused. The computer program for heat exchanger optimization can dramatically reduce the time required in the iterative process to reach an optimum design. In this project, a shell-and-tube heat exchanger (STHE) design program is developed with implementing the state-of-the-art optimization algorithms, non-dominated sorting genetic algorithm (NSGA-II) and teaching-learning based optimization (TLBO), for an effective multi objective optimization procedure.

2. Heat exchanger calculations

The design of STHE involves thermal analysis to determine the dimensions of HE and the heat transfer surface area required. This process is known as the 'sizing' problem and must be solved to meet the requirements of specified hot and cold, inlet and outlet temperatures, flow rates and pressure drop constraints. The Log-Mean-Temperature-Difference (LMTD) method [1] is used in the case of HE sizing problem. The wall thickness of the tubes in the shell is assumed as very thin and hence has zero thermal resistance. In the other hand, the dimensions of HE are already known, but it is to be determined whether HE can deliver the required outlet temperatures, flows rates and stay within pressure drop constraints. It is known as the 'rating' problem and solved by the effectiveness and Number of Transfer Units (ϵ -NTU) method [1].

The pumping power in HE is proportional to HE pressure drop. An increase of the required pumping power leads to an increase of the capital cost due to the increased number or size of the pumps required, and an increase of the operating cost due to the increased required power. Kern method [2] is used to estimate the pressure drop in a shell and tube

HE with the assumption of fully developed incompressible flows in circular ducts. The total cost of HE is the sum of the investment cost and the operating cost over the planned lifecycle. Investment cost for a stainless steel STHE [3] and operating cost [4] based on the electrical cost of running the fluid pumps to overcome the pressure drop are used. The NSGA-II method [5] is chosen as the primary optimization technique due to its robust genetic algorithm approach and its extensive use. The TLBO method [6], which is relatively new, but shows improvements, was also chosen to provide an alternative method.

The input forms have textboxes where the user can enter the constructional design parameters. Fig. 1 shows the main form of the program to present the results of a calculation or an optimization. The results of multi-objective optimization are presented as the graph of the Pareto-optimal front (the effectiveness vs the total cost) (Fig. 2).

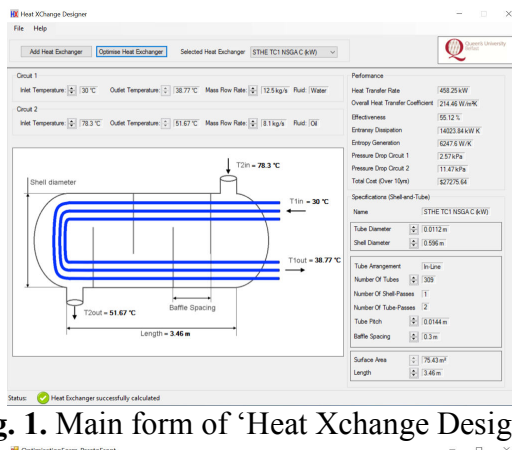


Fig. 1. Main form of 'Heat Xchange Designer'

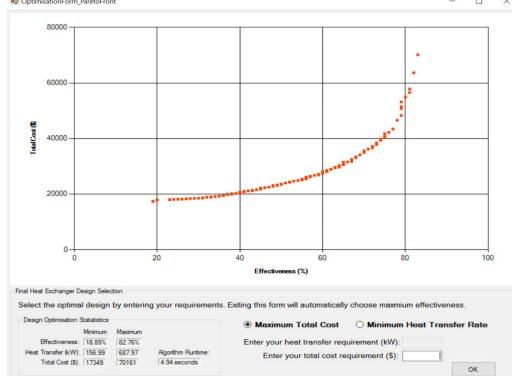


Fig. 2. Pareto-optimal front output form

3. Validation and Results

The solutions of the developed program are compared with the reference cases in Table 1.

The present program is able to provide equivalent STHE design to the reference cases in both of the optimization algorithms. To evaluate the performance of two algorithms, each optimized design is compared in Table 2. The TLBO produced a design with better effectiveness by 2.44% and 55% reduced computing time. More details and additional results will be presented in the conference.

Table 1. Comparison against reference cases

	NSGA-II		TLBO	
	Ref[5]	Present	Ref[6]	Present
Effectiveness	0.6997	0.6998	0.7635	0.7644
Heat duty, kW	578.92	581.74	631.73	635.42
Total cost, \$	33,729	34,619	39,219	41,676

Table 2. Comparison of NSGA-II and TLBO

	NSGA-II	TLBO
Effectiveness	0.5021	0.5265
Heat duty, kW	417.36	437.66
Total cost, \$	23,312	23,392
Number of tubes	217	257
Tube diameter, m	0.0123	0.0112
Shell diameter, m	0.401	0.361
Tube length, m	3.08	3.28

4. Conclusion

The multi objective optimization tool for STHE design has been successfully developed and validated against the reference cases in the literature. Two novel optimization methods, NSGA-II and TLBO, have been implemented. The TLBO method was found to produce better results and more compact STHE design than that of the NSGA-II method.

5. References

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